Conservation management effects on soil erosion reduction in the Sichuan Basin, China

G. Liu, M.J. Lindstrom, X. Zhang, Y. Li, and J. Zhang

ABSTRACT: Water erosion is a serious production problem in the Sichuan province of southwest China. Landscapes are topographically complex with slope gradients up to 40% used for crop production. The present recommended procedure for controlling soil erosion has been through terrace construction. However as slope gradients become greater than 10%, construction costs become prohibitive. Prior research has shown a reduction in water runoff and soil erosion using contour management. The objective of this study was to compare the effects of two contour management systems with the customary up and downslope tillage and planting (ST) on water runoff, soil erosion, and crop production. Experimental sites were established at five locations in Sichuan province. The two contour systems evaluated were a ridge and furrow system established every three years with a no-till planting on the ridge (CTN) for the summer crop and a ridge and furrow system established annually (CT) for the summer crop. The CTN treatment was more effective than CT in reducing water runoff (P = 0.05) at all locations but only significantly more effective in reducing soil erosion at three of the five sites. The contour management systems (CTN and CT) show a significant reduction in water runoff and soil erosion when compared to ST. An estimated practice (P) factor of 0.31 and 0.50 was calculated for the CTN and CT treatments. However, two of the five sites were still experiencing a high rate of soil erosion with contour management, indicating that further erosion control measures may be required.

Keywords: China, contour management, Sichuan province, soil erosion, water runoff

Sichuan province is an agriculturally important area of China. It occupies 6.6% of the cropland but supplies 10% of the agricultural products of China (Li 1993). Major crops produced are rice (*Oryza sativa* L), wheat (*Triticum aestivum* L), corn (Zea mays L), rape (*Brassica napus* L), and sweet potato (*Ipomoea batatus* Lam). The soils developed from weathered purple limestone (Zhang et al. 1995) are shallow, without distinct pedogenic horizons (Orthents), and classified as Regosols in the FAO soil taxonomy and as PupCambols in the China soil taxonomy. Soil depth ranges from 30–150 cm with shallower depths common to the upslope landscape positions. Landscapes are topographically complex with slope gradients up to 40% used for crop production. Production problems associated with this region are soil depth, fertility, drought, and soil erosion. Approximately 40% of the area is susceptible to water erosion. Zhang (1990) measured erosion rates up to 50 t ha^{-1} yr^{-1}.

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The recommended technique for controlling soil erosion has been terrace construction. Level terraces are constructed by digging the limestone bedrock to form terrace boundaries. However, as slope gradients increase above 10%, terraces are expensive and the lack of investment funds in this developing area limits a farmer's ability to construct terraces.

Prior research in China has shown reduction in water runoff from 20–80% and reduction in sediment delivery of 55–75% with contour tillage as compared to straight up and downslope tillage (Shui et al. 1989 and Zhu 1988). Zhu (1988) reported an 80% and 90% reduction in water runoff and sediment transport, respectively, with terrace construction while Jiang et al. (1989) reported only a 10–20% reduction in water runoff and sediment transport. The objective of this study was to compare soil and water loss and crop production from contour tillage with the local customary up and downslope tillage and local cropping management system.

Materials and Methods

This study was conducted at five locations in the Sichuan Province of China (Figure 1), on established runoff plots. At the Yanting site (YT), measurements were made over an 11 yr period (1985 to 1995). At the other sites; Lezhi (LZ), Renshou (RS), Neijiang (NJ), and Jianyang (JY), measurements were made over a seven year period (1989 to 1995). Table 1 shows the soil properties measured at the time of treatment initiation for the five sites. All properties were determined by standard procedures (Head 1980). Soil bulk density was measured with a core sampler, 50 by 50 mm. Organic matter content was determined by dichromate oxidation. Clay content was determined by pipette analysis.

Long term average precipitation ranged between 800–1000 mm yr^{-1} for the study sites. The months of May through September are the primary months for water runoff and soil erosion with 40–45% of the annual precipitation occurring during the months of June, July, and August. Three management systems were established in two replications at each experimental site. Management systems were 1.) contour farming with a seasonal no-till ridge (CTN), 2.) contour till (CT), and 3.) straight tillage (ST).

The CTN treatment was a ridge and furrow system established on the contour every third year. The soil was plowed to 20 cm with farm cattle and then the ridges and furrows were formed by hand labor to build a 100 cm wide ridge and a 100 cm wide furrow along the contour of the slope. Furrow depth was 30 cm. The furrows were plowed to a depth of 20 cm before planting each crop. Sweet potato was no-till planted on the ridges and corn was planted in the furrows for the summer crop. For the winter crop, wheat was planted on the ridges after a shallow tillage and rape was planted in the furrows.

In the contour tillage (CT) treatment, a contour strip cropping sequence of wheat (0.8 m) and rape (0.7 m) was established after plowing to a depth of 20 cm for the winter crop. A ridge and furrow design was then established after moldboard plowing for the summer crops with sweet potato planted on the ridge (0.8 m) and corn in the furrows (0.7 m). The elevation from furrow to ridge was 20 cm. The straight tillage (ST) treatment followed the same procedure as CT except ridge and furrow design ran up and downslope, which is the local custom.

Water runoff and sediment transport were measured from individual plot areas, 4 by 20 m, bounded on three sides by concrete borders. The concrete borders were set to a depth of 0.6 m, defining the contributing area of overland flow and connected to a cement slab at the downslope end of each plot. Water runoff and sediments were piped into a sediment collection tank (4 by 2 by 1 m). A onetenth aliquot of possible overflow from the sediment collection tank was separated by a multi slot divisor and collected in a second collection tank (2 by 2 by 1 m). After each storm, water runoff was determined by measuring the volume of water in the respective tanks. Soil sediment (S) was determined by manually stirring the sediment and water in each tank and collecting dip samples (1000 ml) of the mixture. Sediment samples were precipitated with alum, water was decanted, and then oven dried to determine mass.

Rainfall (R) was measured with a standard rainfall gauge at each site. Rainfall intensity during individual storms was not measured. Individual crop yields for the summer and winter season crops were manually harvested over the entire plot area, cleaned, weighed, adjusted to standard moisture contents, and reported on a per unit land area basis.

Table 1. Selected soil properties measured at initiation for the five experimental sites.

Site	Soil Texture	Bulk Density	Clay Content	Water Stable Aggregates	Organic Matter	Slope Gradient
		$Mg\ m^{-3}$	------	------%	------	------
YT	L	1.38	16.9	7.8	1.10	8
LZ	L	1.46	18.8	8.2	1.12	22
RS	CL	1.41	28.6	5.5	1.05	25
NJ	L	1.35	14.9	15.5	1.15	23
JY	L	1.36	18.4	6.3	1.02	25

Results and Discussion

Table 2 shows the annual soil erosion and runoff coefficients (mm of runoff per mm of rainfall on an annual basis) for the five experimental sites. The statistical ranking of soil erosion and runoff coefficients at the YT site, site with lowest slope gradient (8%) was CTN < CT < ST. The CTN treatment reduced soil erosion and runoff coefficient 62% and 55%, respectively, as compared to ST. The CT treatment showed a reduction in soil erosion and runoff coefficient of 31% and 20%, respectively, when compared to ST.

Average annual soil erosion and runoff coefficient at the other four experimental sites, with steeper slope gradients (22–25%), did not show consistent statistical differences. Differences in soil erosion amounts ($P = 0.05$) between the CTN and CT treatments were observed at the RS and JY sites but not at the LZ and NJ sites. However both the CTN and CT showed a highly significant reduction ($P = 0.01$) in soil erosion when compared to ST, indicating the importance of contour tillage and cropping management versus up and downslope. A reduction in runoff coefficient ($P = 0.05$) was observed between the CTN and CT treatments. The ST treatment again resulted in the greatest runoff coefficient ($P = 0.01$). Although a reduction in soil erosion was observed with the contour management systems, measured annual soil erosion levels at the LZ and JY sites indicate that additional conservation techniques will be required.

Best-fit regression equations were developed to describe the relationships between soil erosion (S, $t\ ha^{-1}\ yr^{-1}$), runoff depth (RD, mm), and rainfall (R, mm) at each location using the form

$$S = a + b \ln R \quad (1)$$

and

$$RD = A + BR \quad (2)$$

where a, b, A, and B are constants, depending on tillage and site characteristics.

The regression coefficients, b and B, for S and RD over the five locations (Table 3) were significantly different from zero at either the P = 0.01 or P = 0.05 level for all tillage systems. The ST tillage systems generally showed the highest regression coefficient followed by CT and then CTN for both soil erosion (S) and runoff depth (RD) within a location. The relative mag-

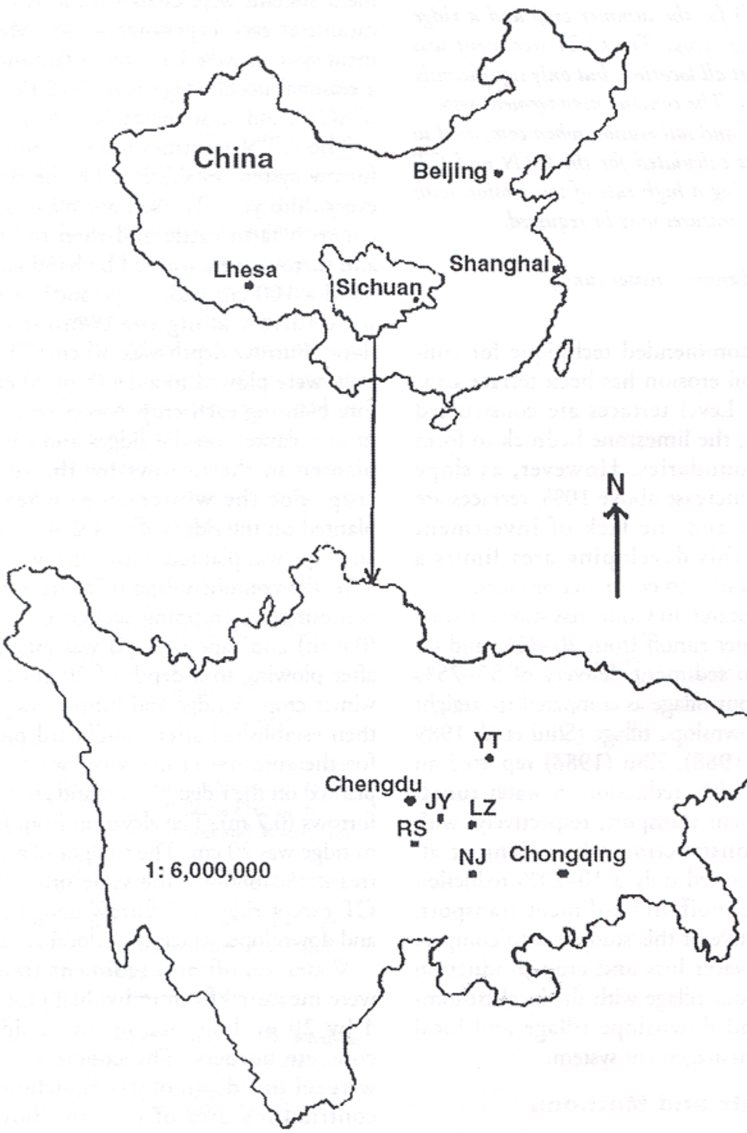

Figure 1. Map of China showing the location of Sichuan Province and the five experimental sites; Yanting (YT), Lezhi (LZ), Renshou (RS), Neijiang (NJ), and Jianyang (JY).

Table 2. Average annual soil erosion and runoff coefficient for the 11 yr study period at the Yanting (YT) site and for the seven year study period at the Lezhi (LZ), Renshou (RS), Neijang (NJ), and Jianyang (JY) sites.

	Tillage System					
	CTN	CT	ST	CTN	CT	ST
Site		Soil Erosion			Runoff Coefficient	
		t ha^{-1}			mm mm^{-1}	
YT	2.7a	4.8b	7.0c	0.09a	0.16b	0.20c
LZ	21.6a	30.0a	67.2b	0.18a	0.20b	0.37c
RS	6.0a	16.8b	42.4c	0.13a	0.16b	0.20c
NJ	4.0a	4.8a	11.8b	0.09a	0.13b	0.22c
JY	26.0a	43.2b	61.6c	0.18a	0.25b	0.27c

Within rows, numbers followed by the same letter are not significantly different, as determined by Fisher's protected LSD (P = 0.05).

Table 4. Estimated practice factor (P value) for the CTN and CT treatments determined by assigning a value of 1 for the ST treatment to the regression coefficient (b) in equation 1 (Table 3).

Sites	CTN	CT	ST
YT	0.48	0.74	1
LZ	0.17	0.24	1
RS	0.14	0.20	1
NJ	0.42	0.55	1
JY	0.33	0.76	1
AVE	0.31	0.50	1

Table 3. Regression coefficients, b and B values from equations 1 and 2, showing the relative susceptibility to soil erosion and water runoff at the five experimental sites as affected by tillage systems and rainfall (R).

Site	Obs No. n	Soil Erosion (b) CTN	CT	ST	Runoff Depth (B) CTN	CT	ST
YT	51	3.0 (1.1)**	4.6 (1.6)**	6.2 (2.0)**	0.12 (0.04)**	0.17 (0.04)**	0.12 (0.03)**
LZ	38	15.3 (4.3)**	21.8 (5.4)**	89.0 (22.2)**	0.24 (0.03)**	0.27 (0.04)**	0.58 (0.07)**
RS	32	8.2 (1.9)*	12.3 (3.2)*	60.4 (13.2)*	0.12 (0.03)*	0.14* (0.04)	0.15 (0.03)**
NJ	26	16.8 (5.4)*	22.3 (7.1)*	40.3 (10.4)*	0.20 (0.04)**	0.31 (0.07)**	0.42 (0.10)**
JY	42	20.2 (5.4)*	46.4 (12.1)*	60.6 (14.0)*	0.24 (0.04)**	0.29 (0.05)**	0.34 (0.05)**

* $P < 0.05$
** $P < 0.01$
Values in parentheses are the standard errors of the estimates.

nitude in regression coefficients between locations is an indication of the water runoff and soil erosion susceptibility.

Differentiating equation 1 gives

$$\partial S/\partial R = b/R \quad (3)$$

suggesting that soil erosion (S) per unit rainfall (R) varies inversely with cumulative rainfall in the hilly terrain of the Sichuan Basin. That is, the amount of soil sediment per unit of rainfall initially increases with the advent of the rainy season and then decreases with the advance of the rainy season. In practice (Figure 2) for the JY site in 1994, soil erosion for the ST treatment per unit of rainfall for individual storms increased rapidly with the advent of the rainy season and then decreased.

The increase can be attributed to rainfall on a poorly protected land surface, in other words, intensively tilled with rows running up and downslope. The subsequent decrease is a factor of crop canopy closure. A similar increase in soil erosion per unit of rainfall was observed with the CTN treatment, but to a lower magnitude. The higher magnitude of soil erosion per unit rainfall indicates that more attention should be focussed on development of conservation techniques for erosion control during the mid-period of the rainy season when rainfall amounts are high and before crop canopy closure.

An estimation of the practice factor (P value) from the Universal Soil Loss Equation (Wischmeier and Smith 1978) for the CTN and CT treatments were determined by assigning a value of 1 to the constant b in equation 1 for the ST treatment and then adjusting the representative constant b for the CTN and CT treatments. Using this type of analysis on the individual runoff plots, the corresponding P values for CTN and CT treatments averaged over the five locations were 0.31 and 0.50, respectively (Table 4), indicating the relative effectiveness of the CTN and CT treatment in reducing soil erosion.

Crop yields averaged over all locations and years are shown in Table 5. Total annual production showed a 19% and 8% increase for the CTN and CT treatments, respectively, over the ST treatment. Crop yields for the CTN treatment was significantly higher than the ST treatment at the P = 0.05 level. The increase in yields for

Table 5. Average annual crop yield over the study period at the five experimental locations.

	Tillage System		
Crops	CTN	CT	ST
		Mg ha^{-1}	
Wheat	3.46a	3.00b	2.67c
Corn	3.59a	3.16b	2.71c
Sweet Potato	11.23a	10.24b	10.01b
Rape	1.38a	1.31b	1.12c

Within rows, numbers followed by the same letter are not significantly different, as determined by Fisher's protected LSD (P = 0.05).

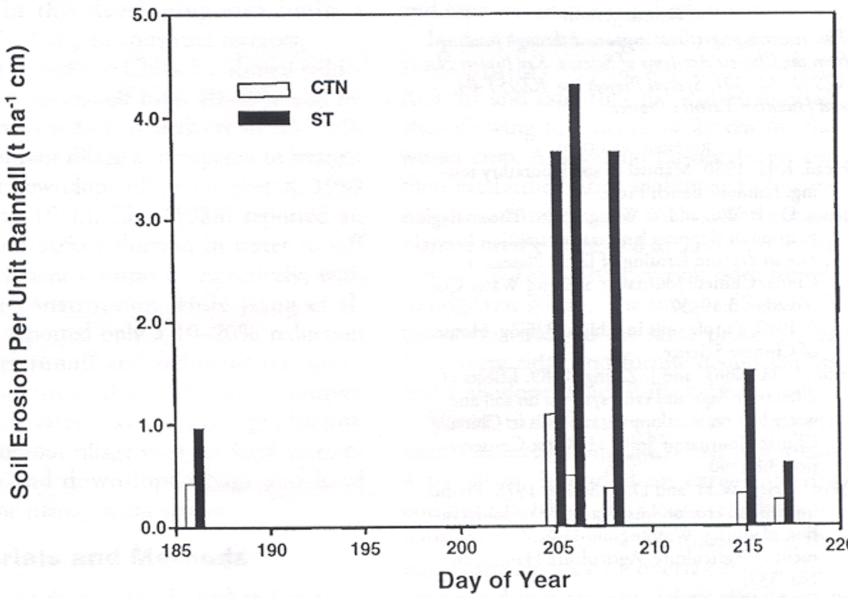

Figure 2. Soil erosion (t ha^{-1}) per unit rainfall (cm) during the 1994 rainy season at the Jainyang (YT) site. Measured canopy cover was 50%, 80%, and 100% on days 185, 205, and 215, respectively.

the contour treatments presumably can be attributed to the reduction in water runoff, allowing greater water use by the crops. This is particularly evident in the increase in yield observed for the crops planted in the furrows (corn and rape).

Conclusion

Water runoff and soil erosion in the Sichuan Basin of China represent a serious problem to sustainable crop production. Present recommended conservation management techniques of terrace construction are not feasible on steep slopes because of prohibitive costs. Contour tillage with a ridge and furrow cropping management system show promise for reducing both water runoff and soil sediment transport. Contour tillage using no-till planting prior to the onset of the rainy season on a maintained ridge in a ridge and furrow system gave the best results by significantly reducing water runoff and soil erosion.

An additional benefit observed with the contour management systems was the increase in crop production. The reduction in water runoff made more water available for crop use and resulted in higher yields, particularly for the crops grown in the furrows.

The customary practice of up and downslope tillage and cropping resulted in high rates of water runoff and soil erosion. This practice should be discontinued in favor of contour management practices; however, additional research is needed to provide technology that can be used to reduce soil erosion during the rainy season when high rainfall amounts are common and before crop canopy closure.

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